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R&D AND FOREIGN SALES IN MULTINATIONALS: A SIMULTANEOUS RELATIONSHIP?

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Abstract - This paper analyzes the simultaneous relationship between R&D and foreign sales in Swedish multinational enterprises in the manufacturing sector. We argue that this two-way relationship should especially apply to multinationals based in small open economies due to the firms' high dependence on foreign markets. The only previous study addressing this issue used data on multinationals originating from the United States, a country with a large domestic market, and it did not find evidence of the hypothesized simultaneous relationship. Our empirical results suggest a positive and significant effect in both directions.

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Keywords: R&D; foreign sales; multinational enterprises

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I. Introduction

In small open economies where firms are dependent on foreign markets for their survival, multinational enterprises (MNEs) often play a pronounced role. In Sweden, for example, MNEs accounted for over 40% of industrial output, around half of overall manufacturing exports and more than 80% of the country's industrial R&D in 1990.

The vast majority of the Swedish multinationals' R&D is undertaken at home, while most of their sales are in foreign markets.[1] This suggests that technologies developed at home to a large extent are exploited abroad. On the other hand, it has been proposed that the expansion in foreign sales by MNEs has enabled the firms to grow large and spend more resources on R&D, and that this has had a positive impact on Sweden's technological base (Håkansson, 1980 and Swedenborg, 1982). Similar arguments have also been raised in the Canadian context by Globerman (1994) and McFetridge (1994). The activities of MNEs may, therefore, be potentially important both for the technological development and international competitiveness of small open economies.

In the theoretical literature on MNEs, a two-way reinforcing relationship between R&D and foreign sales has been suggested by e.g. Caves (1996). Firms with higher R&D outlays, should, *ceteris paribus,* have a technological advantage relative to other firms and, therefore, be more successful in foreign markets. At the same time, an expansion of sales should, in turn, facilitate further R&D investments, since the created knowledge can be utilized to a higher degree.

The only previous empirical study testing the two-way relationship between R&D

[1]By foreign sales is here understood as the sum of parent company exports and net sales by foreign affiliates. Intra-firm sales between a parent company and its foreign affiliates are excluded.

and foreign sales is Hirschey (1981), who used data on MNEs from the United States. He found evidence of a positive impact of foreign sales on R&D, but not the other way around. However, the US is a country with a large domestic market, and we are interested in testing whether Hirschey's results are applicable to small countries, such as Sweden.

In the present study, the simultaneous relationship between R&D and foreign sales in Swedish MNEs is considered. The analysis is based on detailed firm-level data covering practically all Swedish manufacturing MNEs in 1986 and 1990. Our empirical results suggest a positive and significant effect in both directions.

The paper is organized as follows: Theoretical aspects and previous empirical literature regarding R&D and foreign operations are discussed in section II. The data and econometric specification are described in section III, and the exogenous variables are introduced in section IV. The empirical results are presented in section V, and the final section concludes.

II. Theoretical background and earlier studies

Possession of firm-specific advantages is generally argued to be required before a firm is able to penetrate foreign markets (e.g. Hymer, 1960 and Caves, 1971). Such advantages are considered necessary to offset the costs of setting up and operating affiliates across geographical, cultural, or legal boundaries. Firm-specific advantages increase the market concentration and can be derived from factors that create barriers to entry for new competitors, e.g. superior technology, human capital, or product differentiation (Lall, 1980). In particular, firms develop new, and improve existing, products and processes by spending resources on R&D. Successful firms may obtain a technologically based competitive edge relative to competitors, in turn leading to a possible increase in foreign market shares. Several empirical studies have supported such a one-way causal relationship, for example Swedenborg (1982) using Swedish data, Lall (1980) and Kravis and Lipsey (1992) analyzing U.S. data, Greenhalgh (1991) studying U.K. industry data, and Hirsch and Bijaoui (1985) considering an Israeli data set.

Turning to the determinants of R&D expenditures, market structure and factors that create internal or external funds, e.g. profitability, solidity, or cash flow, should be of importance (Caves, 1996). When a firm expands sales, at home or abroad, the R&D-created knowledge will be utilized more extensively, leading to an increased rate of return on each dollar spent on R&D.[2] More internal funds will also be available to finance further R&D projects if the firm earns profits from its foreign operations (Pugel, 1985 and Himmelberg and Petersen, 1994).[3]

A number of studies maintain that there is a positive relationship between R&D activities and firm size, measured as total sales (for a survey, see Cohen and Levin, 1989). These studies argue that large firm size facilitates R&D investment on similar grounds as noted above: higher returns on each R&D dollar spent when the firm has a large volume of sales over which to spread fixed R&D costs (Pakes and Schankerman, 1984), and the ability to raise funds for risky R&D projects. For MNEs in small countries, there is less scope to finance R&D investments by sales in the home market alone. Foreign markets will, thus, be essential for expansion as well as for the financing of R&D activities. If a firm has a large country as its home-base, for instance the United

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[2]Mansfield *et al.* (1979) reports that MNEs based in the United States expect to earn over 30% of the returns on R&D through utilization of the technology in foreign markets. This percentage is likely to be even higher for firms based in a small open economy.

[3]It has been argued that large firms have greater possibilities to raise external funds for R&D. This capacity should, however, be related to the solidity and profitability of the firm and not to size *per se*.

States or Japan, the arguments are weaker.

The study by Hirschey (1981), mentioned above, tested the causal relationship between R&D and foreign sales in a simultaneous model using data on US multinationals. He found no support for a simultaneous relationship between R&D and foreign sales, but only that foreign sales had a positive impact on R&D expenditures.[4]

Foreign markets can be served either through exports from the parent company or by production in foreign affiliates. We do not know of any studies directly evaluating what role R&D plays in the choice between exports and foreign production. According to the product cycle theory (Vernon, 1966), the choice depends on the historical phase of the product. R&D aimed at developing new products and processes should primarily result in exports from the home country, while R&D aimed at improving existing products and processes should tend to favor foreign production.

III. Data and econometric method

The data on Swedish MNEs used in the empirical analysis has been collected by the Industrial Institute for Economic and Social Research (IUI) in Stockholm. Practically all Swedish-owned firms in manufacturing with more than 50 employees and with at least one majority-owned producing affiliate abroad are included in the data set.[5] Data for 1986 and 1990 are pooled in the analysis, yielding a sample of 202 observations, of which 88 are taken from the 1986 survey and 114 from the 1990 survey. A total of 147

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[4]In a related study (Hughes, 1985), using U.K. industry level data, the simultaneity between R&D and exports was taken into account. The results suggest that R&D has a positive effect on exports. The reverse impact how exports affect R&D activities; however, was not tested.

[5]It could be argued that the sample should also contain firms without production facilities abroad, but data for such firms was not available. However, many small firms with a single facility abroad, and that have had production abroad for only a few years, are also included in our sample. These small MNEs represent a group of firms with limited foreign operations.

different MNEs are analyzed, of which 55 are included twice, and 92 once, in the sample.

When relating R&D to foreign operations, previous studies have used several different measures. For example, intensities have been compared with absolute levels and foreign operations have often been represented by exports. In the present study, the two main variables are defined as follows:

***RD/TS*:** R&D intensity, which equals the firm's total R&D expenditures, *RD*, divided by total sales, *TS*. This is the standard measure of technological intensity (see e.g. Scherer, 1980).

***FS/TS*:** Share of total sales in foreign markets. Foreign sales, *FS*, is here defined as parent company exports plus net sales by foreign affiliates (intra-firm sales between a parent company and its foreign affiliates are excluded). We argue that *FS* is a better measure of the firm's international activities than either exports or affiliate sales. Like *RD* above, *FS* is divided by *TS*, to obtain the foreign sales intensity.

The use of intensities controls for historical factors of the MNEs as well as for firm size, and is also a way to reduce heteroscedasticity in the regression analysis. A positive relationship is expected between firm *i*'s R&D intensity, RD_{it}/TS_{it}, and its degree of internationalization, FS_{it}/TS_{it}, at time *t*.[6] The model characterizing the relationship between these two variables is specified as follows:

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[6]Since today's R&D will not yield profits or enhance competitiveness until future time periods, it could be argued that a time lag should be used in the R&D variable. Time lags in the regression variables are, however, always a problem in cross-section analysis. The use of time lags would also have reduced the sample considerably (from 202 to 55 observations). Furthermore, firms' R&D intensities are rather stable in the short or medium term. For example, the Pearson correlation coefficient between R&D intensities for 55 firms included in both surveys 1986 and 1990 was estimated to 0.83, and significant at the 1% level.

$$\frac{FS_{it}}{TS_{it}} = \beta_0 + \beta_1 \frac{RD_{it}^{*}}{TS_{it}} + Z_1'\beta + \epsilon_{it} , \qquad \textbf{(1)}$$

$$\frac{RD_{it}^{*}}{TS_{it}} = \gamma_0 + \gamma_1 \frac{FS_{it}}{TS_{it}} + Z_2'\gamma + \mu_{it} , \qquad \textbf{(2a)}$$

$$\frac{RD_{it}}{TS_{it}} = \begin{cases} \dfrac{RD_{it}^{*}}{TS_{it}} & if \ \dfrac{RD_{it}^{*}}{TS_{it}} > 0 \\ 0 & if \ \dfrac{RD_{it}^{*}}{TS_{it}} \leq 0 \end{cases} . \qquad \textbf{(2b)}$$

The residuals are assumed to have the desired properties: $\varepsilon \sim N(0,\sigma_\varepsilon^2)$ and $\mu \sim N(0,\sigma_\mu^2)$,$E(\varepsilon_{it}\varepsilon_{jt})=0$ and $E(\mu_{it}\mu_{jt})=0$ for $i \neq j$.[7] However, $E(\mu_{it}\varepsilon_{it}) \neq 0$, since a simultaneous relationship is expected between *RD/TS* and *FS/TS*. The hypothesis of no simultaneity was tested, and rejected, using a Hausman (1978) test.

The method used to estimate the interactions between *RD/TS* and *FS/TS* is a variant of 2SLS with limited endogenous variables, outlined in Nelson and Olson (1978). OLS can be used to estimate the reduced and structural form of equation (1). The other endogenous variable, *RD/TS*, is, however, characterized by some concentration of zeroes (about 18%), i.e. the firms with no R&D expenditures. When estimating equation (2) in the first and second stage of 2SLS, the Tobit method is therefore employed.[8]

The latent variable, $(RD/TS)^*$, can be interpreted as an index of R&D intensity, of which *FS/TS* is a function. The *Z*'s are vectors including firm and industry-specific

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[7]It should be noted that $E(\mu_{is}\mu_{it}) \neq 0$ and $E(\varepsilon_{is}\varepsilon_{it}) \neq 0$ for $s \neq t$. A firm with a high R&D intensity in time *s*, is also expected to have a high R&D intensity in time *t*. Although not taken into account in the estimation procedure, the parameter estimates will not be inconsistent. Most firms are only observed once in the sample, implying that this possible autocorrelation should not be a serious problem.

[8]There may be a separate process determining whether a firm undertakes any R&D from how much R&D the firm does, given that it has a R&D facility. In such case, a Heckman (1976) two-step procedure would be appropriate for equation (2). To our knowledge, no simultaneous Heckman procedure is available.

attributes, while the β's and γ's denote parameters or vectors of parameters showing the impact of the explanatory variables on the dependent variable. The simultaneous Tobit method yields consistent parameter estimates, but the asymptotic standard errors of the parameter estimates are underestimated. In order to correct for this, the asymptotic variance-covariance-matrix is derived and the standard errors recalculated according to Amemiya (1979).

The parameters in equation (1) are marginal effects. The estimate of γ_1 in the Tobit equation cannot be interpreted as a marginal effect on the actual dependent variable *RD/TS*, however.[9] Rather, it is a combination of the marginal effect on the R&D intensity and the effect on the probability that the firm will undertake any R&D at all (McDonald and Moffitt, 1980).[10] The parameters β_1 and γ_1 show the direct effect of one intensity on another. The marginal effect of R&D on foreign sales, and vice versa, can be obtained by the following formulas (derived in appendix A);

$$\frac{\partial FS}{\partial RD} = \frac{\beta_1}{1 - A}, \quad \text{where } A = \beta_0 + Z_1'\beta . \tag{3}$$

$$\frac{\partial^* RD}{\partial^* FS} = C + \gamma_1, \quad \text{where } C = \gamma_0 + Z_2'\gamma . \tag{4}$$

The ∂^* in equation (4) denotes the marginal *and* probability effect of *FS* on *RD*.

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[9] γ_1 is a marginal effect of *FS/TS* on the latent variable $(RD/TS)^*$.

[10] The marginal effect of *FS/TS* on *RD/TS*, $\partial(RD/TS)/\partial(FS/TS)$, simply equals $F(z)\gamma_1$, where $F(z)$ is the cumulative normal distribution and $z = X'\gamma/\sigma_\mu$. X is a vector of explanatory variables and γ is the vector of estimated Tobit parameters. The z is calculated around the means of X.

IV. Exogenous variables

In the following, we present the exogenous variables in the model, their definitions and expected impact on the two dependent variables. The explanatory variables included in equation (1), except for high initial capital costs and the size of the home market, are related to firm-specific advantages. These factors have been investigated in earlier empirical studies (e.g. Lall, 1980 and Swedenborg, 1979 and 1982). The explanatory variables in equation (2) are related to market structure and the possibilities to raise funds for R&D. Table 1 summarizes the explanatory variables included in each equation.[11] The signs (+ or -) show the expected effects on the dependent variable.

***HIC*:** High initial capital costs at the plant level (*HIC*) is defined as the average plant size, measured as the average book value of equipment, tools, and real estate of a MNE's foreign affiliates.[12] We assume that plant level capital costs are partly industry-specific and therefore exogenous in the model. Since *HIC* makes it costly for new firms to enter the market, we expect it to be positively associated with *FS*/*TS*. However, we do not expect that *HIC* is related to *RD*/*TS*.[13]

***LS*:** Labor skills. MNEs endowed with human capital in terms of a skilled labor force should have an advantage relative to other firms. *LS* is measured as the average wage in the Swedish operations of the MNEs, and is expected to have a positive

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[11]See Table 10 in appendix B for definitions, means and standard deviations of variables.

[12]This definition is made under the assumption that each affiliate operates at the optimal level of scale. No data is available for the plant size of the MNEs' domestic plants.

[13]We do not know of any empirical evidence of a relationship between the variables *HIC* and *RD*/*TS*. Firms operating e.g. in basic industries often have high initial capital requirements, but low R&D intensity. On the other hand, certain firms in chemicals may be characterized by high R&D intensity and small plants.

influence on *FS/TS*.[14] Even if the wage level to some extent is a choice variable for the firm, we treat *LS* as exogenous in the model, because the wage setting on the Swedish labor market is largely determined by industry-level bargaining. The wage dispersion across firms in a certain job category should therefore be limited. Thus, *LS* rather reflects the composition of the labor force, which is partly industry specific.

***HOME*:** Size of the home country market. Empirical observations on Swedish and other small-country MNEs indicate that they are more international than MNEs originating from larger countries. *HOME* is included in equation (1), and we expect that a small home market forces firms to locate a large share of their sales in foreign markets. Hence a negative effect is expected on *FS/TS*. The variable *HOME* is measured as total industry sales in million SEK on the Swedish market for the product groups of the MNE.

***CONC*:** World market concentration. Firms operating in concentrated industries are more inclined to compete using strategies other than price, including R&D, advertising, and product differentiation. *CONC* is measured as the sum of the world market shares of the four largest firms in the industry where the MNE's largest division operates.[15] A positive effect of *CONC* on R&D intensity is expected. *CONC* is not included in equation (1) since it is regarded more as an outcome of various oligopolistic advantages rather than a cause of such advantages. The world market concentration is

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[14]We use the Swedish average wage, since the average wage for the whole MNE is largely influenced by the income levels in the different host countries where the firms operates. Hence, we compare the wage levels of firms in the same country.

[15]The "world market" defined by the MNEs corresponds to the 5-digit, or more detailed, ISIC industrial classification.

taken to be exogenous in the empirical model.[16]

PROFIT: gross profit margin, defined as operating income before depreciation and financial items divided by total sales. A higher profit implies a greater ability to raise internal funds to finance R&D projects. We expect *PROFIT* to exert a positive impact on firms' R&D intensity. Again, it can be discussed whether this variable is exogenous in the model. We argue that this is reasonable, considering that a firm's profit level for a certain year will to a large extent be influenced by business cycles and stochastic shocks.[17] The reason to include *PROFIT* is mainly for the fund raising capacity in one point in time, and not the MNEs long term profitability or survival, for example.

With regard to absolute firm size, we argue that size *per se* should not confer a distinct firm-specific advantage, but is rather a consequence of oligopolistic advantages, e.g. scale economies. Some previous studies have claimed that there is a positive relationship between size and R&D intensity (Cohen and Levin, 1989). In analyzing the simultaneous relationship between R&D and foreign sales, Hirschey (1982) included firm size in the R&D equation, but found no significant effect. Moreover, Cohen *et al.*, (1987) concluded that overall firm size is not significantly related to R&D intensity. We have therefore not included size in our basic model. However, a variant is estimated, including firm size, measured as total employees (*EMP*).[18]

In the empirical analysis we use dummy variables to control for fixed industry

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[16]Although the market concentration may be endogenously determined in the long run, it is here regarded as predetermined. The *world market concentration* for a given industry is rather stable, and only to a limited degree affected by the actions of individual firms.

[17]Analysis of individual Swedish firms' profitability over time produces a very irregular pattern.

[18]Ideally, we should measure firm size as total sales, *TS*, but this variable would partly be endogenous since it includes foreign sales, *FS*.

and time effects which may influence the level of *FS/TS* and *RD/TS*.[19] Furthermore, by including interaction dummies, we also examine whether the estimated parameters for the endogenous variables, β_1 and γ_1, are different for industries undertaking R&D aimed for *product* and *process* innovations, respectively. R&D undertaken in the engineering and pharmaceutical industries is assumed to be primarily aimed for product innovations, while R&D in iron & steel, paper & pulp, textiles, food, cement, and wood, is assumed to be basically geared towards process innovations.

Finally, with regard to exogenous variables, a few comments on the issue of rival R&D are appropriate, even if we have not included any such explicit variable. Theoretically, the issue of competitors' R&D interaction is not fully settled. Depending on whether the firms' R&D are substitutes or complements, and if spillovers are important, a rival's R&D may either increase, decrease or have no effect on the R&D expenditures of a firm. In addition, an empirical application would require detailed data on rival R&D, which is not available. Most of the Swedish MNEs have their major competitors abroad, and only in a handful cases can we identify firms which are close rivals. An interesting observation is that rivals tend to have approximately the same R&D intensities.[20] By means of the industry dummies discussed above, we have to some extent taken into account rival R&D, even if a more detailed analyis of this issue would have been interesting.

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[19]An additive time dummy for 1986 and additive dummies for the following industries are included in all estimations: food, textile, basic chemicals, pharmaceuticals & advanced chemicals, paper & pulp, iron & steel, metal products, machinery, electronics, transport equipment and "other industries". Since an individual firm is never included more than twice in the pooled sample, it is not possible to analyze firm-specific effects.

[20]There are around 10 cases in the data set where two or more firms are close rivals, e.g. pharmaceuticals, transport equipment, paper, pulp and wood products, machinery, textile, and cement.

V. Empirical results

The results of the simultaneous estimation are provided in Tables 2 and 3 below. As shown in Table 2, the estimated parameters of *RD/TS* and *FS/TS* in equations (1) and (2), respectively, are both positive, and significantly different from zero at the 1% level, using a two tailed t-test.[21] By calculating the marginal effects according to equations (3) and (4), the direct effect of an increase in *RD* on *FS*, and vice versa, is obtained. The first row in Table 3 indicates that both $\partial FS/\partial RD$ and $\partial^* RD/\partial^* FS$ are significant at the 1% level. This may suggest that R&D expenditures increase sales in foreign markets and that sales abroad in turn facilitate R&D. Thus, R&D expenditures and foreign sales seem to reinforce each other in accordance with our main hypothesis.

Considering the estimated derivatives for the two groups "product R&D" and "process R&D" in Table 3, we notice that $\partial FS/\partial RD$ is significant at the 1% level in the product-group and at the 5% level in the process group. It is also noted that the difference in the parameter estimate between the two groups is not significant (see Table 6, appendix B). The difference is, however, significant for $\partial^* RD/\partial^* FS$. The marginal effect for product R&D is significant at the 1% level, while it is not significant for process R&D, meaning that we cannot tell if a change in *FS* affects *RD* in this group. Hence, the two-way relationship between R&D and foreign sales is only verified in the product R&D group. In the concluding section we discuss possible explanations for this result.

With regard to the exogenous variables in the model (Table 2), we first observe

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[21]In the main econometric model we do not decompose foreign sales into parent exports and affiliate net sales. However, estimations that included parent company exports (*EXP*) and affiliate net sales (*FQ*) were also undertaken, with three equations instead of two. Equation (1) was estimated twice with *EXP/TS* and *FQ/TS*, respectively, as dependent variables. The results were not satisfactory since multicollinearity arose in equation (2) in the second stage of 2SLS.

for the foreign sales equation that the variable measuring high initial capital costs, *HIC*, is positively related to *FS/TS*, as expected. The parameter is significant at the 5% level. The estimated parameters for *LS*, labor skill in the MNE, and *HOME*, size of the home market for the firm's products, are not significant in the foreign sales equation.[22]

Turning to the R&D equation, we see that world market concentration, *CONC*, is positively associated with *RD/TS*. The estimated parameter is, however, only significant at the 10% level. Thus, there is weak evidence that concentration favors competition by R&D. Finally, the parameter of the profit variable, *PROFIT*, also has the expected positive sign, and is significant at the 5% level, indicating that internal fund raising may be important in a firm's decision to undertake R&D.

As discussed in section IV, we also estimate a variant of the model with firm size measured as total number of employees (*EMP*), as an exogenous variable in the R&D equation. However, *EMP* did not turn out to be significant, and did not alter the results for the other variables, as can be seen from Table 8 in appendix B.

VI. Conclusions

This paper analyzed the simultaneous relationship between R&D and foreign sales in Swedish multinationals in manufacturing. Positive and statistically significant effects were found in both directions, supporting the hypothesis of a two-way reinforcing relationship. The only previous study explicitly addressing this issue used data for U.S. manufacturing firms, but did not find evidence of a simultaneous relationship. This may

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[22]One possible explanation for the poor performance of *LS* may be that the average wage is not an appropriate indicator of labor skill; however, no alternative measure was available in our data set. Measurement problems in *HOME* may also have affected the results. First, *HOME* is the only variable in our data that is taken from a source other than the IUI survey. Second, the firms' classification of product groups did not correspond exactly to the official industrial classification system (ISIC).

suggest that the link between R&D and foreign sales is stronger for MNEs originating from small home economies, and that the relationship is weaker for firms from countries with large home markets. Industrial firms from small countries have limited growth opportunities in their home markets, and hence are more dependent on foreign sales.

When analyzing product- and process-related R&D separately, proxied by the MNE's industry classification, the two-way relationship is only found for product R&D. The weaker relationship in the process group may be explained in part by the fact that the major R&D investors are found in product industries. Another reason may be that product innovations are essentially associated with entry into new product markets, while process R&D aims to reduce the costs of producing a given range of products. Moreover, Mansfield (1984) suggests that firms are more hesitant to utilize their process technologies abroad as compared with their product technologies. In a patent context, he argues that once process technologies go abroad, it is difficult to determine whether foreign firms are illegally imitating them.

Since the present study analyzes only what is taking place at the firm level, we are limited in our abilities to draw policy conclusions. However, in the case of small MNE-dependent countries, it is plausible that; (i) disadvantages relating to firms' incentives to undertake R&D, such as unfavorable tax treatment of R&D or a limited supply of qualified researchers, may in the long term erode the home country's international competitiveness, while (ii) any eventual regulations constraining firms' foreign expansion could lead to reduced R&D, most of which is undertaken at home, implying the possibility of a slower technological development. Future research should more directly attempt to assess the impact of multinational activity on a home country's international competitiveness and technological development.

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Table 1. Explanatory variables included in each equation and the expected impact on the dependent variable

		Dependent variable	
Explanatory variables	Description	*FS/TS* Equation (1)	*RD/TS* Equation (2)
RD/TS	Total R&D / Total sales	+	
FS/TS	Foreign sales / Total sales		+
HIC	High initial costs	+	
LS	Labor skill	+	
HOME	Size of home market	-	
CONC	Market concentration		+
PROFIT	Profit margin		+

Note: Definitions, means and standard deviations for the variables are available in Table 10, appendix B.

Table 2. Results of simultaneous estimations

Method = Simultaneous Tobit	Dependent variable	
	FS/TS	*RD/TS*
Explanatory variables	Equation (1)	Equation (2)
RD/TS	5.18 *** (1.31)	---
FS/TS	---	0.083 *** (0.033)
HIC	6.54 E-4 ** (3.08 E-4)	---
LS	-0.394 (0.485)	---
HOME	-4.46 E-6 (4.05 E-6)	---
CONC	---	2.29 E-4 * (1.39 E-4)
PROFIT	---	0.078 ** (0.034)
Adjusted R^2	0.35	---
F-value	8.37	---
Log-likelihood ratio	---	118.8
Number of observations	202	202
Left-censored obs.	---	34

Note: ***, ** and * indicate significance at 1, 5 and 10 percent level, respectively, using a two tailed t-test. Standard errors in parentheses. Intercepts, dummies for time and industries are shown in Table 4, appendix B. First-stage estimates are shown in Table 5, appendix B.

Table 3. Estimated derivatives for the main variables, total and across industries

Estimated derivatives	$\partial FS/\partial RD$	$\partial^* RD/\partial^* FS$
Industries	Equation (3)	Equation (4)
All industries (n=202)	11.14 *** (1.87)	0.048 *** (0.013)
"Product-R&D" group (n=104)	6.03 *** (1.79)	0.044 *** (9.26 E-3)
"Process-R&D" group (n=98)	10.35 ** (5.01)	2.73 E-3 (0.0226)
Significant difference between industries?	No	Yes

Note: ***, ** and * indicate significance at 1, 5 and 10 percent, respectively, using a two tailed t-test. Standard errors in parentheses. The estimated derivative equals the marginal effect in equation (3), but the marginal *and* probability effect in equation (4). The original regressions with industry estimates are available in Tables 6 and 7, appendix B.

Appendix A

The marginal effect of an increase in *RD* on *FS*, can be derived by first separating total sales, *TS*, in equation (1) into foreign, *FS*, and domestic sales, *DS*

$$\frac{FS}{FS + DS} = A + \beta_1 \frac{RD}{FS + DS} , \qquad \textbf{(A1)}$$

$$where\ A = \beta_0 + Z_1'\beta ,$$

$$TS = FS + DS .$$

After that we solve for *FS:*

$$FS = \frac{1}{1 - A} (A\ DS + \beta_1 RD) . \qquad \textbf{(A2)}$$

This gives the partial derivative:

$$\frac{\partial FS}{\partial RD} = \frac{\beta_1}{1 - A} . \qquad \textbf{(A3)}$$

In a similar way, the effect of *FS* on *RD* can be derived:

$$\frac{\partial^* RD}{\partial^* FS} = C + \gamma_1 , \qquad \textbf{(A4)}$$

$$where\ C = \gamma_0 + Z_2'\gamma .$$

In this case, ∂^* indicates the total partial effect (marginal and probability effect). *A* and *C* are calculated around the means of Z_1 and Z_2.

The standard error of $\partial FS/\partial RD$ is then calculated, using a first-order linear approximation, according to Blom (1980):

$$\sigma_{\partial FS\,/\,\partial RD} = \sqrt{Var\left(\frac{\beta_1}{1 - A}\right)} = \sqrt{Var\ (\ g\ (\beta_0, \beta_1, ..., \beta_k))} \qquad \textbf{(A5)}$$

$$= \sqrt{\sum_{i=0}^{k} Var(\beta_i) \left(\frac{\partial g}{\partial \beta_i}\right)^2 + 2 \sum_{i=0,\, i<j}^{k} Cov(\beta_i, \beta_j) \left(\frac{\partial g}{\partial \beta_i}\right) \left(\frac{\partial g}{\partial \beta_j}\right)} ,$$

where

$$\frac{\partial g}{\partial \beta_1} = \frac{1}{1 - A} ,$$

$$\left.\frac{\partial g}{\partial \beta_i}\right|_{i \neq 1} = \frac{\beta_1}{(1 - A)^2} X_i .$$

The standard error of $\partial^* RD / \partial^* FS$ is calculated in a similar manner:

$$\sigma_{\partial^* RD / \partial^* FS} = \sqrt{\sum_{i=0}^{k} Var(\gamma_i) \left(\frac{\partial h}{\partial \gamma_i}\right)^2 + 2 \sum_{i=0,\, i<j}^{k} Cov(\gamma_i, \gamma_j) \left(\frac{\partial h}{\partial \gamma_i}\right) \left(\frac{\partial h}{\partial \gamma_j}\right)} , \qquad \textbf{(A6)}$$

where

$$h = h\,(\gamma_0, \gamma_1, \ldots, \gamma_k) ,$$

$$\frac{\partial h}{\partial \gamma_1} = 1 ,$$

$$\left.\frac{\partial h}{\partial \gamma_i}\right|_{i \neq 1} = X_i .$$

Appendix B

Table 4. Supplement to Table 2. Second-stage estimates of dummies for time and industries

Method = Simultaneous Tobit	Dependent variable	
	FS/TS	*RD/TS*
Explanatory variables	Equation (1)	Equation (2)
Intercept	0.650 *** (0.090)	-0.060 *** (0.016)
Time dummy 1986	0.026 (0.037)	6.25 E-4 (4.51 E-3)
Dummy food industry	-0.281 *** (0.077)	0.024 * (0.014)
Dummy textiles	-0.048 (0.082)	6.44 E-3 (0.011)
Dummy basic chemicals	-0.035 (0.071)	5.10 E-3 (9.10 E-3)
Dummy pharmaceuticals & advanced chemicals	-0.178 ** (0.073)	0.032 *** (7.85 E-3)
Dummy non-electrical machinery	0.094 * (0.055)	-3.42 E-3 (8.01 E-3)
Dummy electrical machinery	-0.114 * (0.073)	0.020 ** (8.99 E-3)
Dummy transport equipment	-0.140 (0.122)	0.038 *** (0.012)
Dummy paper & pulp	-9.51 E-3 (0.070)	-1.59 E-4 (8.12 E-3)
Dummy iron & steel	-0.052 (0.108)	6.84 E-3 (0.013)
Dummy other industries	-0.128 ** (0.060)	0.014 (9.31 E-3)

Note: ***, ** and * indicate significance at 1, 5 and 10 percent level respectively. Standard errors in parentheses. The metal products industry is the reference group for the industry dummies.

Table 5. Supplement to Table 2. First-stage estimates

Method = Simultaneous Tobit	Dependent variable	
	FS/TS	*RD/TS*
Explanatory variables	Equation (1)	Equation (2)
Intercept	0.448 ***	-0.040 ***
	(0.072)	(0.010)
HIC	1.06 E-3 ***	7.10 E-5 **
	(2.43 E-4)	(3.20 E-5)
LS	0.294	0.124 **
	(0.371)	(0.050)
HOME	-2.64 E-6	1.84 E-7
	(3.60 E-6)	(4.79 E-7)
CONC	2.96 E-3 ***	4.70 E-4 ***
	(6.09 E-4)	(8.11 E-5)
PROFIT	0.021	0.071 **
	(0.213)	(0.031)
Time dummy 1986	0.071 **	7.71 E-3 *
	(0.030)	(4.08 E-3)
Dummy food industry	-0.305 ***	-2.43 E-3
	(0.067)	(9.01 E-3)
Dummy textiles	-0.052	1.97 E-3
	(0.071)	(9.99 E-3)
Dummy basic chemicals	-0.039	1.31 E-4
	(0.062)	(8.21 E-3)
Dummy pharmaceuticals &	-0.017	0.029 ***
advanced chemicals	(0.053)	(7.09 E-3)
Dummy non-electrical	0.102 **	4.43 E-3
machinery	(0.048)	(6.39 E-3)
Dummy electrical machinery	-0.030	0.019 **
	(0.060)	(8.09 E-3)
Dummy transport equipment	0.042	0.034 ***
	(0.093)	(0.013)
Dummy paper & pulp	-0.044	-6.25 E-3
	(0.058)	(8.17 E-3)
Dummy iron & steel	-0.086	-7.62 E-3
	(0.094)	(0.013)
Dummy other industries	-0.074	9.28 E-3
	(0.052	(6.96 E-3)
Adjusted R^2	0.36	---
F-value	8.12	---
Log-likelihood ratio	---	126.72
Number of observations	202	202
Left-censored obs.	---	34

Note: ***, ** and * indicate significance at 1, 5 and 10 percent level respectively. Standard errors in parentheses. The metal products industry is the reference group for the industry dummies.

Table 6. Results of simultaneous estimations for industries dealing with product and process R&D. Second-stage estimates

Method = Simultaneous Tobit	Dependent variable			
	FS/*TS*		*RD*/*TS*	
	Equation (1)		Equation (2)	
Explanatory variables	Parameter	Std. error	Parameter	Std.error
RD/*TS*	2.56 ***	0.940	---	---
(*RD*/*TS*)×Dummy Process	2.23	2.95	---	---
FS/*TS*	---	---	0.071 ***	0.025
(*FS*/*TS*)×Dummy Process	---	---	-0.116 ***	0.017
HIC	9.40 E-4 ***	3.05 E-4	---	---
LS	0.291	0.477	---	---
HOME	-5.36 E-6	4.47 E-6	---	---
CONC	---	---	2.53 E-4 **	1.11 E-4
PROFIT	---	---	0.051 *	0.029
Intercept	0.540 ***	0.090	-0.050 ***	0.013
Time dummy 1986	0.056	0.037	3.04 E-3	3.79 E-3
Dummy food industry	-0.302 ***	0.080	0.056 ***	0.012
Dummy textiles	-0.056	0.083	0.063 ***	0.013
Dummy basic chemicals	-0.017	0.084	0.076 ***	0.014
Dummy pharm. & adv. chemicals	-0.148 *	0.084	0.082 ***	9.45 E-3
Dummy non-electrical machinery	0.122 **	0.056	-2.82 E-3	6.60 E-3
Dummy electrical machinery	-0.067	0.073	0.019 **	7.57 E-3
Dummy transport equipment	-0.025	0.121	0.037 ***	9.80 E-3
Dummy paper & pulp	-0.063	0.071	0.072 ***	0.013
Dummy iron & steel	-0.072	0.126	0.066 ***	0.014
Dummy other industries	-0.130	0.072	0.074 ***	0.011
Adjusted R^2	0.32		---	
F-value	6.84		---	
Log-likelihood ratio	---		152.40	
Number of observations	202		202	
Left-censored obs.	---		34	

Note: ***, ** and * indicate significance at 1, 5 and 10 percent level respectively. First-stage estimates are shown in Table 7. The metal products industry is the reference group for the industry dummies.

Table 7. Results of simultaneous estimations for industries dealing with product and process R&D. First-stage estimates

Method = Simultaneous Tobit	Dependent variable			
	FS/TS		*RD/TS*	
	Equation (1)		Equation (2)	
Explanatory variables	Parameter	Std. error	Parameter	Std.error
HIC	1.29 E-3 ***	4.26 E-4	1.67 E-5	4.50 E-5
HIC×Dummy Process	-3.38 E-4	5.21 E-4	1.53 E-5	5.51 E-5
LS	0.059	0.469	0.236 ***	0.050
LS×Dummy Process	0.214	0.535	-0.297 ***	0.058
HOME	-5.92 E-6	5.37 E-6	2.01 E-6 ***	5.62 E-7
HOME×Dummy Process	3.87 E-6	7.11 E-6	-2.58 E-6 ***	7.55 E-7
CONC	3.84 E-3 ***	8.55 E-4	3.10 E-4 ***	9.21 E-5
CONC×Dummy Process	-1.89 E-3	1.23 E-3	-6.43 E-5	1.31 E-4
PROFIT	4.27 E-3	0.268	0.076 **	0.034
PROFIT×Dummy Process	-0.048	0.437	-0.060	0.050
Intercept	0.474 ***	0.080	-0.060 ***	8.81 E-3
Time dummy 1986	0.070 **	0.031	4.81 E-3	3.29 E-3
Dummy food industry	-0.298 ***	0.102	0.067 ***	0.011
Dummy textiles	-0.059	0.103	0.065 ***	0.011
Dummy basic chemicals	0.020	0.104	0.073 ***	0.011
Dummy pharm. & adv. chemicals	-0.045	0.079	0.082 ***	8.37 E-3
Dummy non-electrical machinery	0.077	0.051	0.010 *	5.43 E-3
Dummy electrical machinery	-0.041	0.061	0.022 **	6.58 E-3
Dummy transport equipment	0.035	0.114	9.59 E-3	0.012
Dummy paper & pulp	-0.043	0.101	0.071 ***	0.011
Dummy iron & steel	-0.076	0.142	0.081 ***	0.015
Dummy other industries	-0.067	0.090	0.075 ***	9.56 E-3
Adjusted R^2	0.36		---	
F-value	6.34		---	
Log-likelihood ratio	---		152.40	
Number of observations	202		202	
Left-censored obs.	---		34	

Note: ***, ** and * indicate significance at 1, 5 and 10 percent level respectively. The metal products industry is the reference group for the industry dummies.

Table 8. Results of the simultaneous estimations when total firm size is included in equation (2). Second-stage estimates

Method = Simultaneous Tobit	Dependent variable			
	FS/TS		*RD/TS*	
	Equation (1)		Equation (2)	
Explanatory variables	Parameter	Std.error	Parameter	Std.error
RD/TS	5.31 ***	1.291	---	---
FS/TS	---	---	0.084 *	0.044
HIC	6.39 E-4 **	3.10 E-4	---	---
LS	-0.417	0.485	---	---
HOME	-4.39 E-6	4.07 E-6	---	---
CONC	---	---	2.26 E-4	1.63 E-4
PROFIT	---	---	0.079 **	0.035
EMP	---	---	-2.20 E-8	1.76 E-7
Intercept	0.653 ***	0.089	-0.060 ***	0.225
Time dummy 1986	0.025	0.037	5.80 E-4	4.66 E-3
Dummy food industry	-0.281 ***	0.077	0.024	0.016
Dummy textiles	-0.047	0.081	6.53 E-3	0.011
Dummy basic chemicals	-0.036	0.072	5.07 E-3	9.06 E-3
Dummy pharm. & adv. chemicals	-0.182 **	0.073	0.032 ***	7.85 E-3
Dummy non-electrical machinery	0.093 *	0.055	-3.49 E-3	8.43 E-3
Dummy electrical machinery	-0.116	0.072	0.020 *	0.011
Dummy transport equipment	-0.146	0.123	0.039 ***	0.013
Dummy paper & pulp	-7.92 E-3	0.069	7.69 E-5	8.15 E-3
Dummy iron & steel	-0.053	0.108	6.94 E-3	0.013
Dummy other industries	-0.129 **	0.061	0.014 *	8.48 E-3
Adjusted R^2	0.36		---	
F-value	6.52		---	
Log-likelihood ratio	---		146.46	
Number of observations	202		202	
Left-censored obs.	---		34	
Estimated derivatives	Parameter	Std.error	Parameter	Std.error
$\partial FS/\partial RD$	11.36 ***	1.89	---	---
$\partial^* RD/\partial^* FS$	---	---	0.049 ***	0.017

Note: ***, ** and * indicate significance at 1, 5 and 10 percent level respectively. First-stage estimates are shown in Table 9. The metal products industry is the reference group for the industry dummies.

Table 9. Results of the simultaneous estimations when total firm size is included in equation (2). First-stage estimates

Method = Simultaneous Tobit	Dependent variable			
	FS/TS		*RD/TS*	
	Equation (1)		Equation (2)	
Explanatory variables	Parameter	Std. error	Parameter	Std.error
HIC	8.71 E-4 ***	2.66 E-4	5.95 E-5 *	3.48 E-5
LS	0.282	0.370	0.123 ***	0.050
HOME	-3.42 E-6	3.62 E-6	1.34 E-7	4.83 E-7
CONC	2.89 E-3 ***	6.08 E-4	4.66 E-4 ***	8.09 E-5
PROFIT	0.018	0.212	0.071 **	0.031
EMP	1.58 E-6	9.64 E-7	9.67 E-8	1.26 E-7
Intercept	0.458 ***	0.072	-0.039 ***	9.99 E-3
Time dummy 1986	0.068 **	0.030	7.54 E-3 *	4.08 E-3
Dummy food industry	-0.300 ***	0.067	-2.09 E-3	9.00 E-3
Dummy textiles	-0.051	0.070	2.02 E-3	9.98 E-3
Dummy basic chemicals	-0.033	0.062	5.33 E-4	8.22 E-3
Dummy pharm. & adv. chemicals	-0.014	0.053	0.030 ***	7.09 E-3
Dummy non-electrical machinery	0.096 **	0.048	4.08 E-3	6.40 E-3
Dummy electrical machinery	-0.072	0.065	0.016 *	8.86 E-3
Dummy transport equipment	-0.021	0.098	0.032 **	0.013
Dummy paper & pulp	-0.038	0.058	-5.83 E-3	8.16 E-3
Dummy iron & steel	-0.075	0.094	-6.96 E-3	0.013
Dummy other industries	-0.074	0.052	9.27 E-3	6.95 E-3
Adjusted R^2	0.37		---	
F-value	7.88		---	
Log-likelihood ratio	---		152.40	
Number of observations	202		202	
Left-censored obs.	---		34	

Note: ***, ** and * indicate significance at 1, 5 and 10 percent level respectively. The metal products industry is the reference group for the industry dummies.

Table 10. Definitions, means and standard deviations for the variables included in the model.

Variable	Definition	Mean	Std. deviation
RD/TS	R&D intensity: Total R&D expenditures divided by total sales. *RD* and *TS* are expressed in nominal SEK.	0.020	0.029
FS/TS	Foreign sales intensity: Foreign sales divided by total sales. Foreign sales is defined as the sum of parent company exports and foreign affiliate net sales (intra-firm sales between a parent company and its foreign affiliates are excluded in *FS*). *FS* and *TS* are expressed in nominal SEK.	0.621	0.244
HIC	High initial costs. Average plant level book value of equipment, tools and real estate in a MNE's foreign plants. Expressed in 1990 SEK prices (million).	35.53	65.92
LS	Average wage level in the parent company. Expressed in 1990 SEK prices (million).	0.170	0.041
HOME	Size of the Swedish home market for the firm's product groups, measured by industry sales. Expressed in 1990 SEK (million). *Source*: Statistics Sweden 1986 and 1990).	6760	6313
CONC	Concentration. Sum of world market concentration for the four largest firms in the industry in which the firm's largest division operates (percent).	32.19	26.52
PROFIT	Gross profit margin. Operating income before depreciation and financial items divided by total sales. Operating income and *TS* are expressed in nominal SEK.	0.103	0.072